Agent-based Modeling Capability for Integrated CNS-NAS Simulation

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- Why Agent-based CNS Modeling?
- Modeling of CNS Entities as Agents
  - Communication
  - Navigation
  - Surveillance
- Modeling CNS Functionality at the Agent Infrastructure Level
- Summary

Why CNS Modeling?

- Communication Systems
  - What is the delay between source and sink in a network or a set of networks under different characteristic conditions, such as
    - Number of nodes
    - Traffic
    - Transmission medium
    - Protocol
- Navigation Systems
  - What is the accuracy of navigational information when using hybrid systems (GPS and VOR/DME) under conditions such as:
    - Loss of signals (signal jamming)
    - Drifts and clock drifts (in case of GPS)
- Surveillance Systems
  - What is accuracy of state information in using different systems due to
    - Delay
    - Radar malfunction
    - Signal interference

Why Agent-based CNS Modeling?

- An agent-based design is characterized by software that
  - *Encapsulates local state*
  - *Independent execution*
  - ***Message and event driven behavior***. Agents interact with the world and with other agents by communicating through some well defined set of messages, events and protocols
- Implementation of a Message-based communication approach “mimics” real world communications between “entities” modeled as agents
- Separation of the messaging scheme from “business logic” enable one to incorporate CNS models into software with minimal code rewrite
- Mixed -fidelity modeling of CNS aspect

Why Agent-based CNS Modeling ?

- Can leverage existing Agent-based simulation software such as ACES enabling an integrated approach to studying the impact of CNS aspects on performance.

- Can now address questions such as
  - What is the impact of the CNS infrastructure on the performance of a new Airspace concept?
  - What aspects of the concept need to be addressed to ensure robust performance under a given CNS architecture?
  - Given a particular concept, what is the impact of different CNS infrastructures on the performance of the NAS?
  - What are the limitations, (in terms of bandwidth, delays etc) of the CNS infrastructure as flight demand increases, security overlays are introduced?
  - What are the impacts on safety in the event of CNS failures?

Why Agent-based CNS Modeling ?

- An agent-based simulation approach provides the ideal test-bed environment to perform both pure simulation and hardware-in the loop experiments

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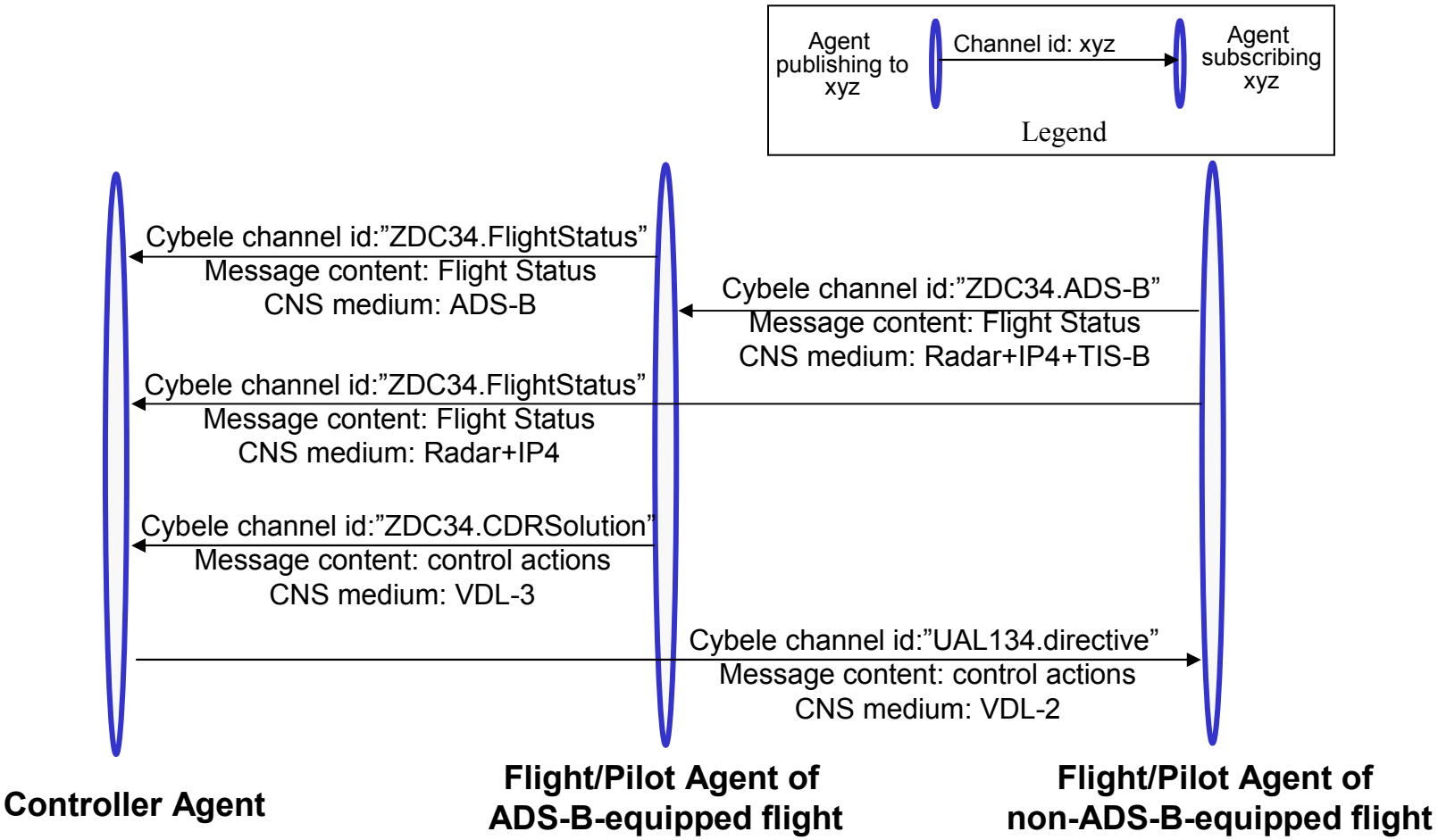
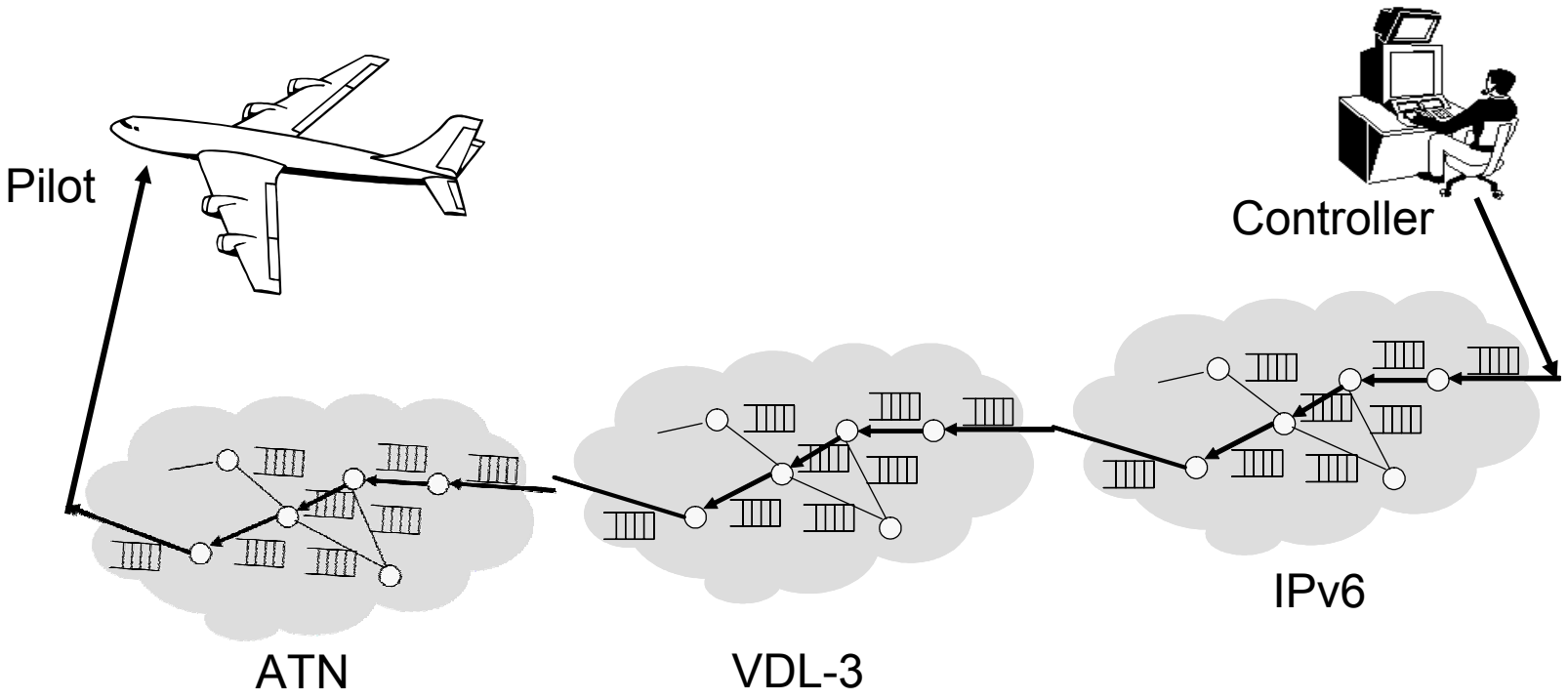
Agent Communication

(Self Separation between ADSB and non-ADSB Flights)



Communication System Modeling



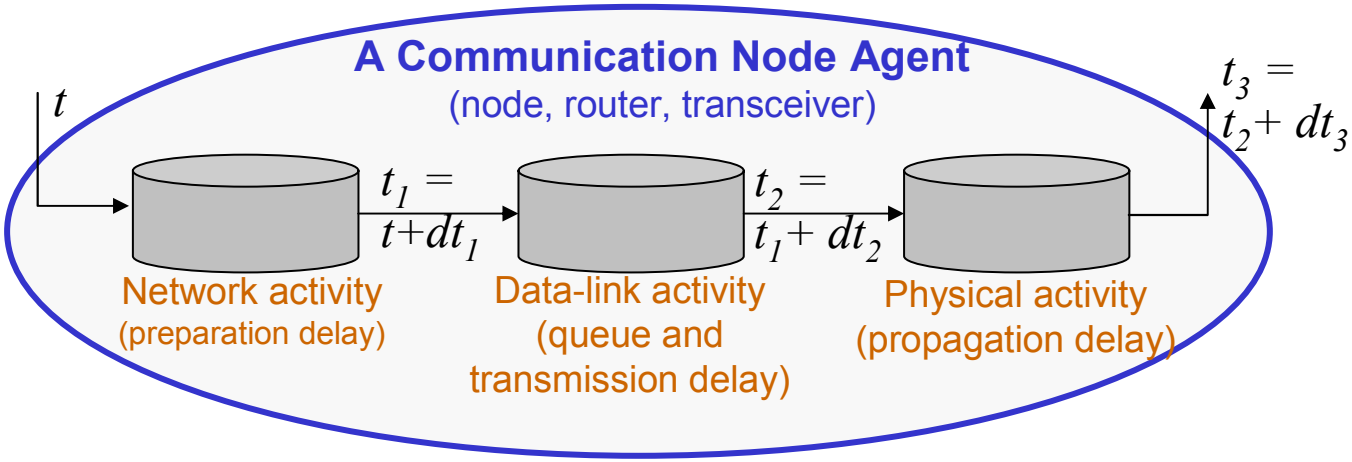
There is a finite amount of delay between the time when a message is issued and when it is received

Different Types of Delays in a Communication Node

- Processing delay
  - The time taken to encode voice or data into packets
  - The time taken to examine the header
- Queue delay
  - The time spent by packets in a queue waiting to be transmitted by data-link layer of OSI model
- Transmission delay
  - Delay depends on packet length and transmission rate (10Mbps or 100Mbps)
  - Affected by flow control, collision and multiple access channel (for wireless network) protocols
- Propagation delay
  - Depends on the distance between nodes and the medium (fiber, radio etc.)

Agents & Activities in Communication System Model

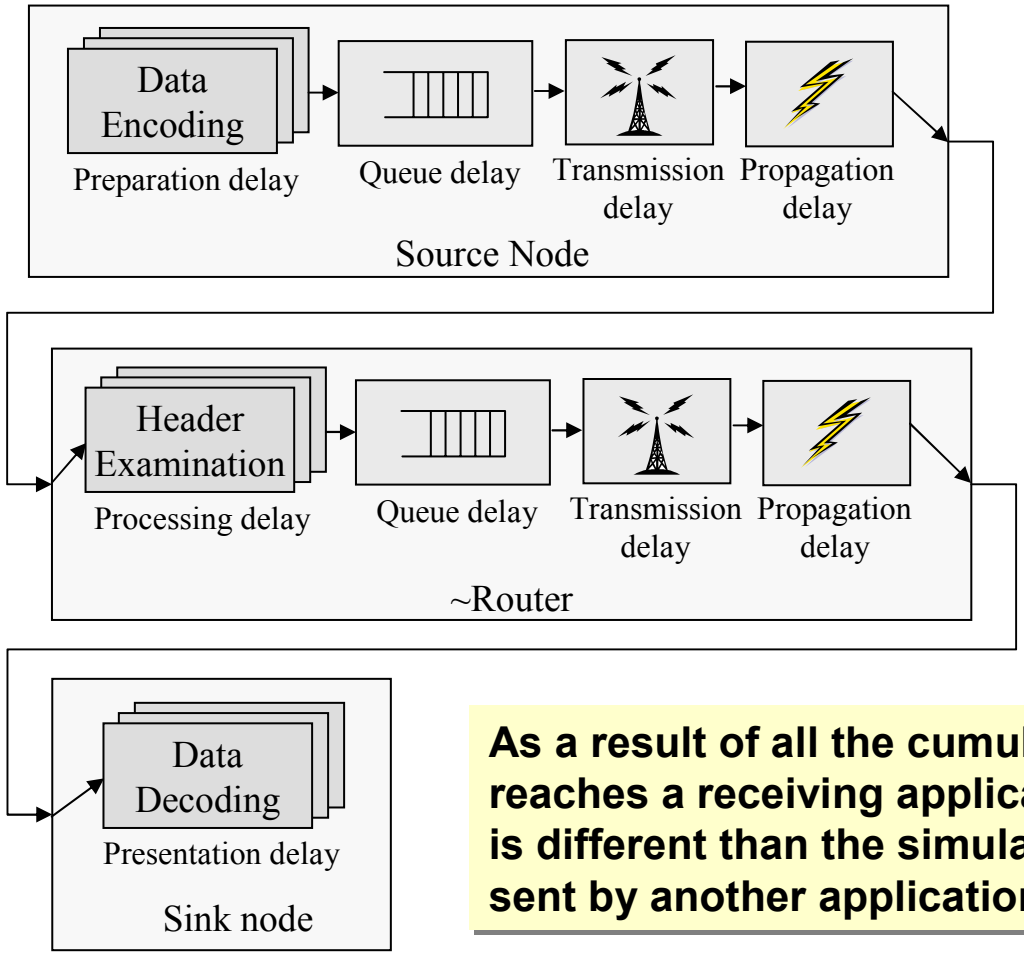
- A node, router or transceiver is an agent
- Each agent has at least three activities introducing different delays in the message delivery
  - The total simulated delay reflects the time taken by a node to forward a packet to the next node since it received the packet



Delay Modeling

- Network Activity
  - For a router, a constant delay is introduced that is proportional to the time taken examining the header and placing the packet in a queue
  - For a source node, delay is computed based on data size and type of encoding used
  - For a sink node, delay is computed based on time taken in decoding and compiling all packets
- Data-link Activity
  - Uses collision, flow control and MAC models to compute *variable* transmission delay
  - The models take traffic volume into consideration
  - The queue delay occurs due to finite transmission service time
- Physical Activity
  - Adds a constant delay based on the medium and distance between the nodes

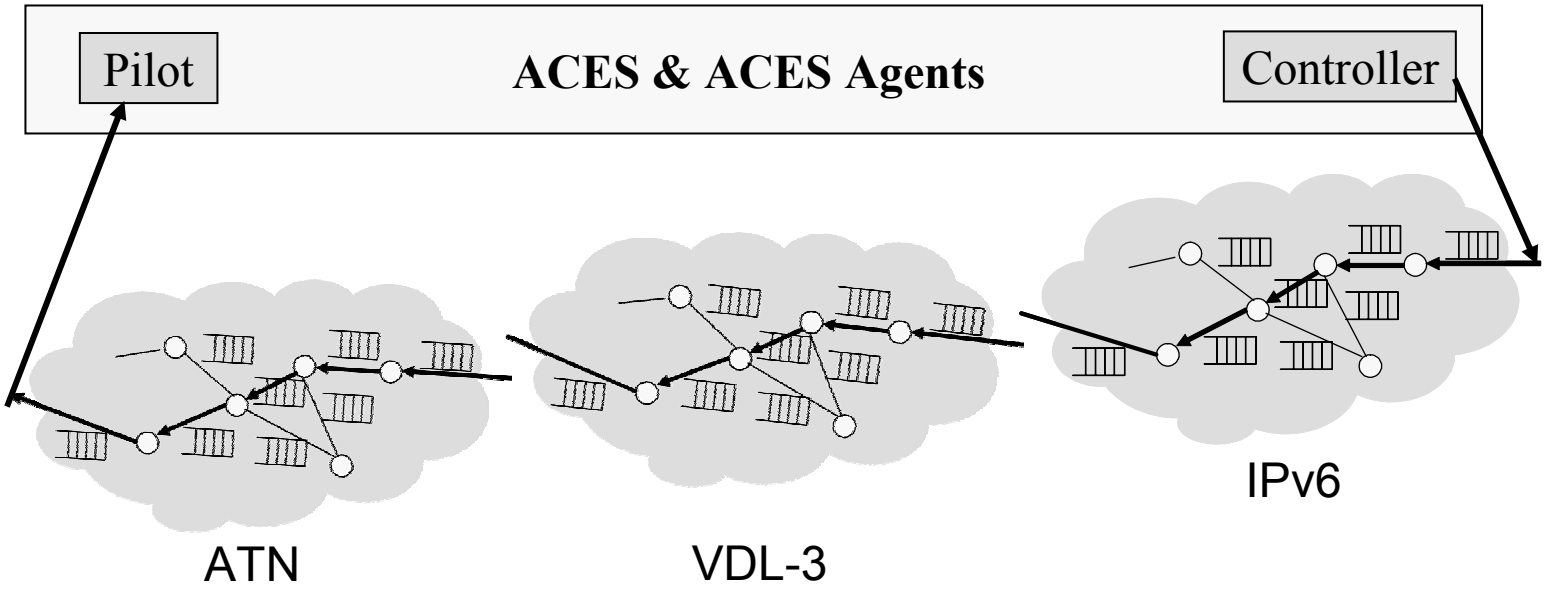
End-to-End Delay in the Network



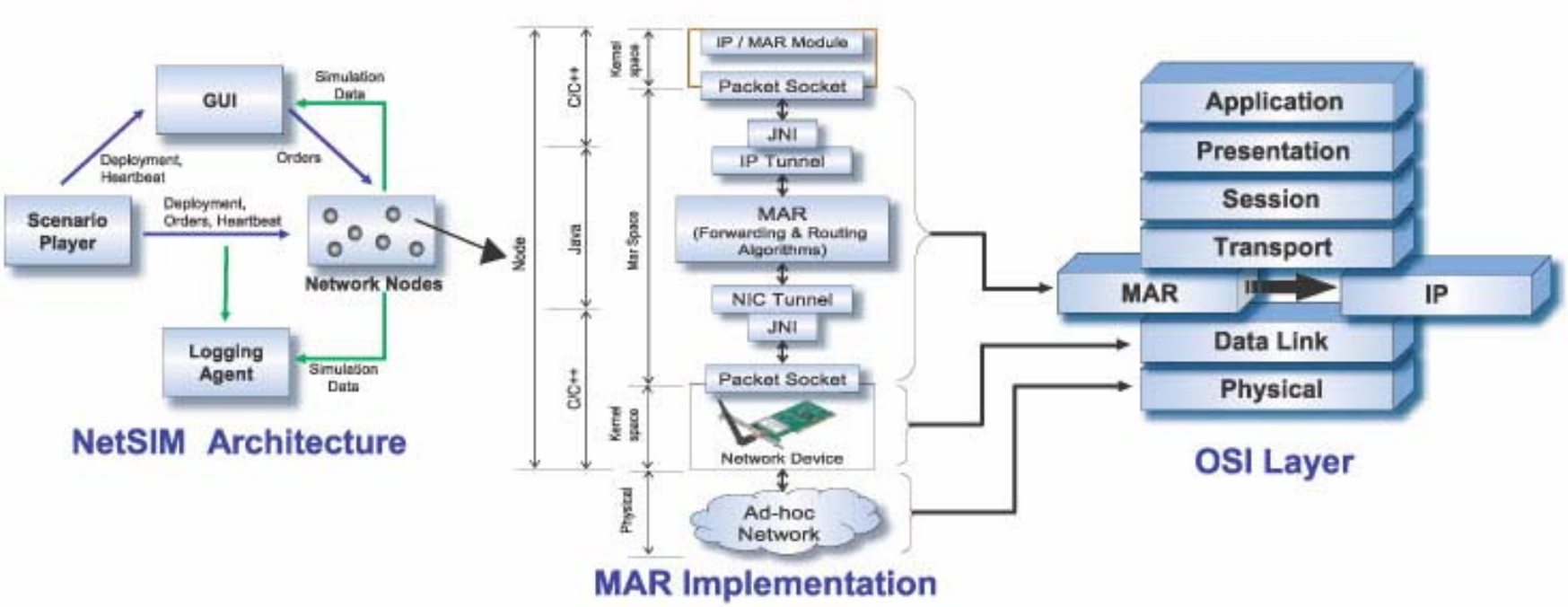
As a result of all the cumulative delays, the packet reaches a receiving application at a simulation time that is different than the simulation time at which packet is sent by another application

Impact of Agent-based Delay Model on NAS

- Pilot agent receives a Controller directive after elapse of a simulated time
- A direct correlation between degradation of a particular communication system on the NAS safety and throughput can be established
- Allows hardware-in-loop simulation for validating modeling accuracy



IAI's Agent-based Ad-Hoc Network Simulation



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Ground-based Navigation (VOR/DME, VORTAC)

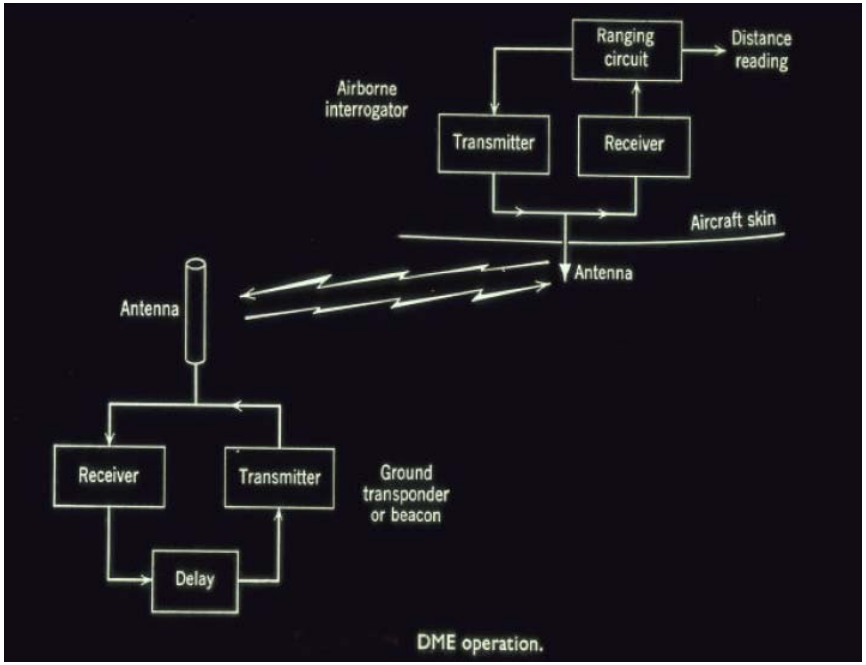
- What impacts navigation
  - Line of sight requirement
  - Error in calibrated delay
  - Atmospheric conditions

$$\text{Slant Distance} = C(T - \delta)/2$$

C = Light velocity

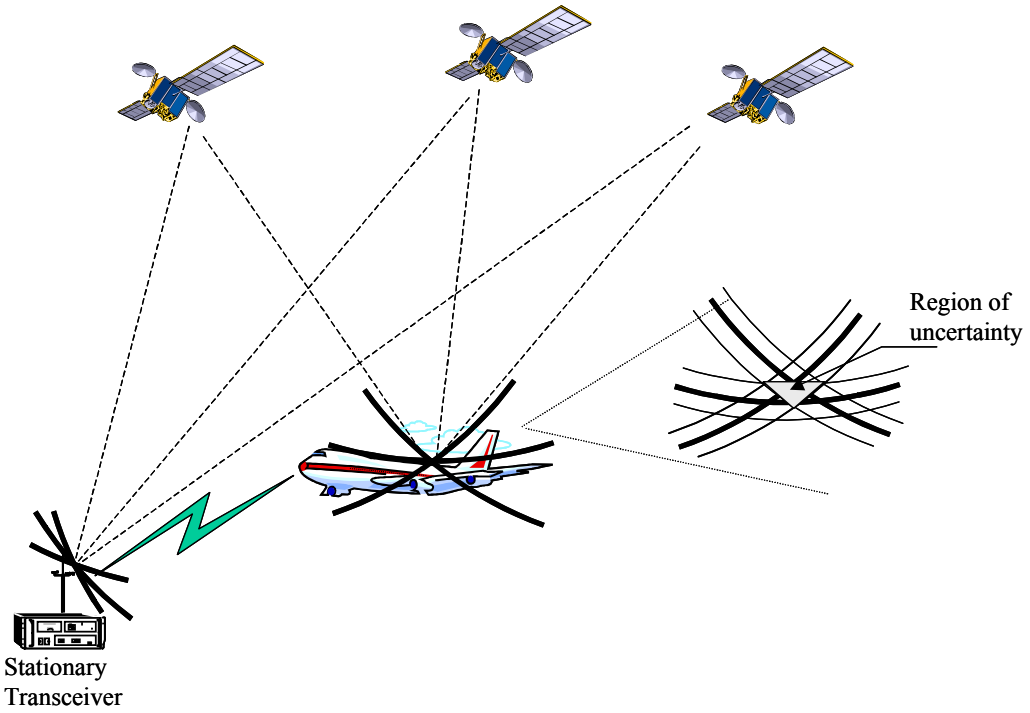
T = Elapsed time

δ = Response delay



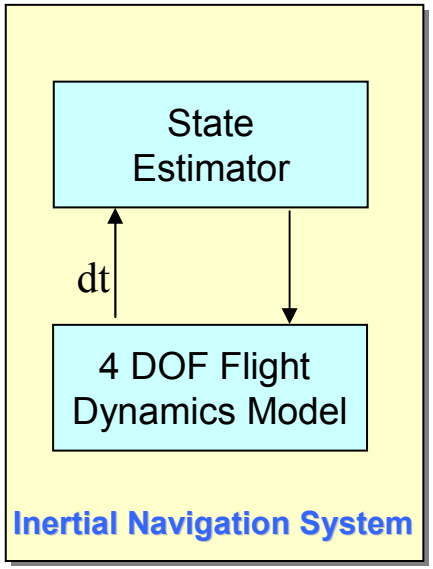
Space-based navigation (GPS)

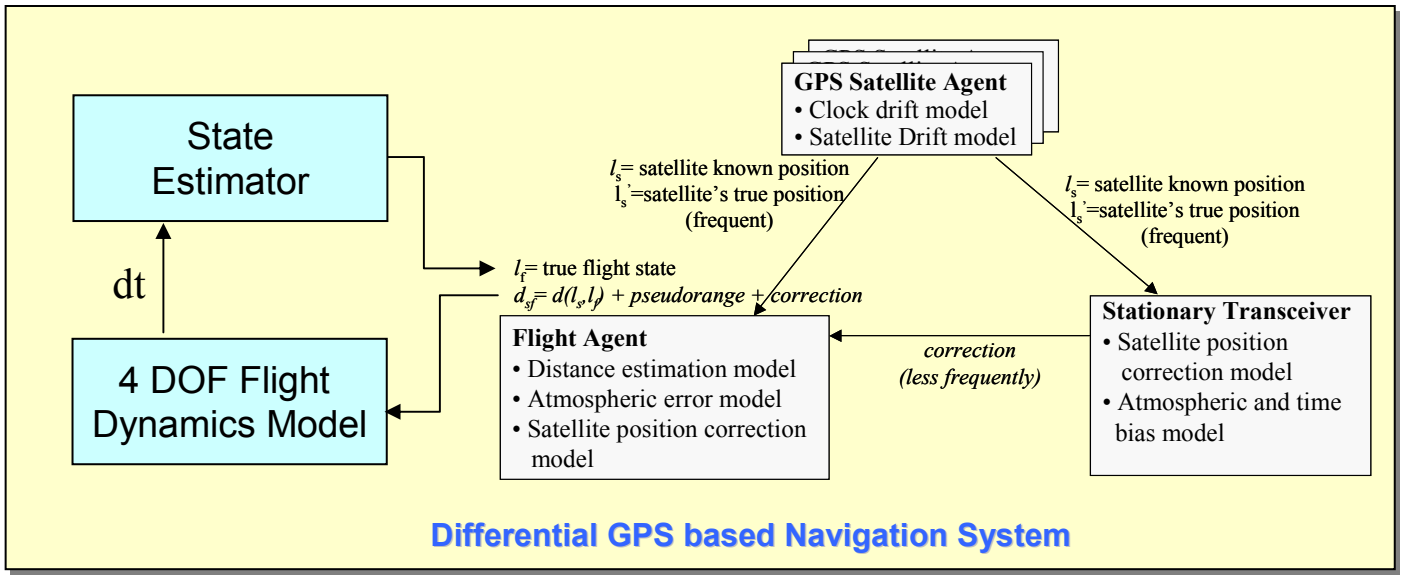
- What impacts navigation
  - Drift (satellite & clock)
  - Signal loss (jamming)
  - Atmospheric conditions



Agent-based Modeling of GPS Navigation

- GPS Agent
  - Activity broadcasting drift and location
- Flight Agent
  - Activity computing pseudeoranges for SE
- Stationary Transceiver Agent
  - Activity broadcasting differential corrections





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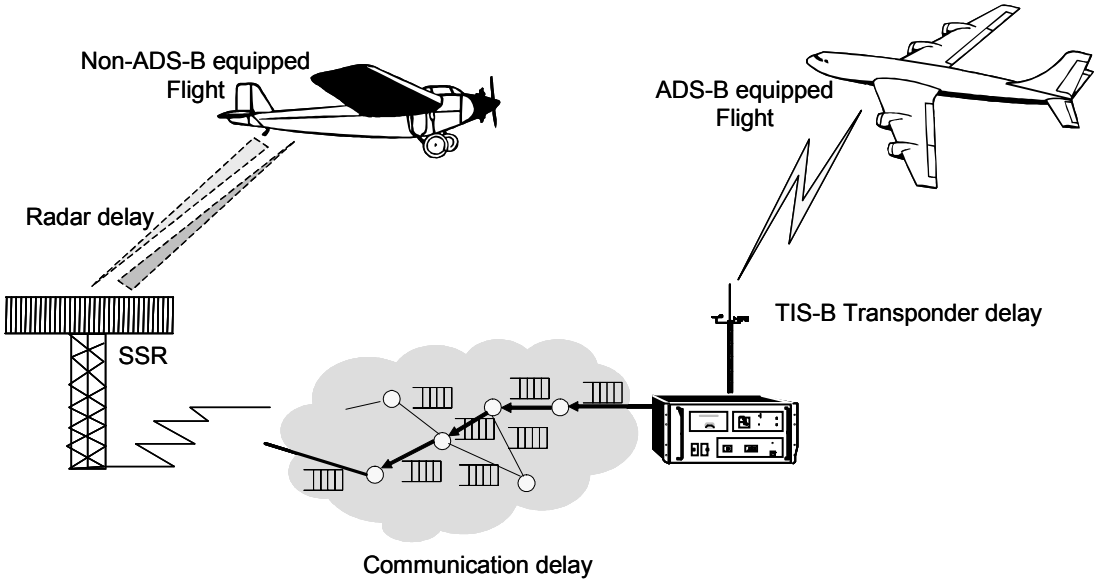
Surveillance Systems

- Primary Radar
  - Atmospheric (signal) attenuation
  - Weather
  - Range
- Secondary Radar
  - Signal loss in response
  - Response delay
- ADS-B
  - Communication delay
- TIS-B
  - Communication delay
  - Signal loss

Surveillance System Modeling for Self Separation Concept – A Schematic

- The location of non-ADSB equipped flight as gathered by SSR is fed to ADSB equipped flight after the elapse of finite time – delay
- The delay attributed due to SSR, Communication network and TIS-B transponder can be modeled using agents
  - SSR and transponders need to be modeled as agents
  - Atmospheric attenuation/error models can be developed for SSR to add location uncertainty
  - Delay models for each agent can be developed to add location correction



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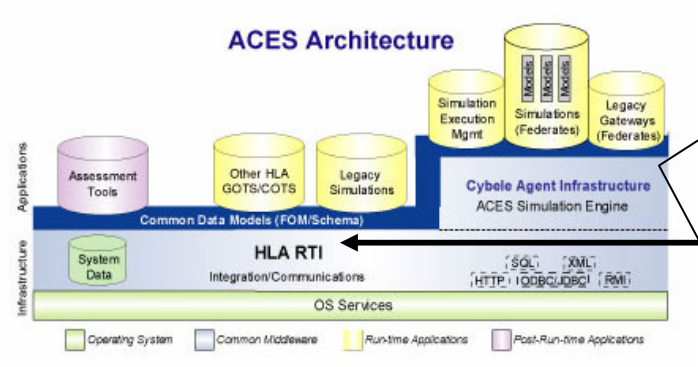
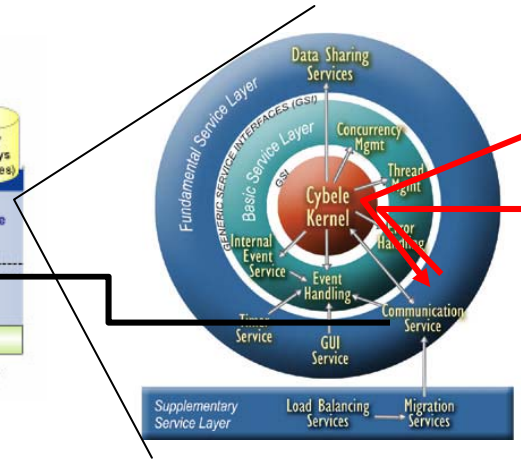
CNS Modeling within Agent Infrastructure

- Cybele-HLA as Agent Infrastructure for ACES Simulation

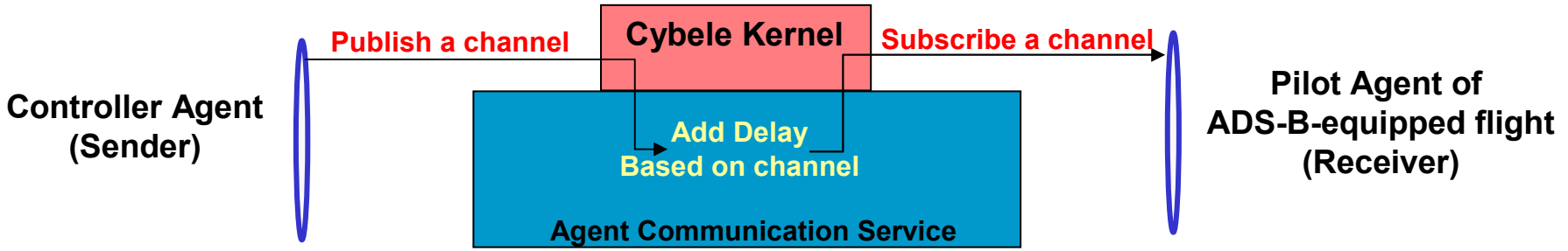




Service-layered Architecture of Cybele

Controller Agent (Sender)

Pilot Agent of ADS-B-equipped flight (Receiver)



Pros and Cons of Agent Infrastructure Support for CNS

- Advantages (compared to CNS entities modeled as agents)
  - NAS simulation and model development need not be coupled with CNS modeling
  - Mostly well suited for communication systems where number of agents tend to be large
- Disadvantages (compared to CNS entities modeled as agents)
  - Inability to easily introduce new models as development at the infrastructure level tends to be significantly more complex
  - Can impact efforts that require hardware in the loop simulation

Summary

- An integrated approach to modeling and simulation that considers both NAS domain models and the underlying CNS infrastructure is needed to truly evaluate new concepts and new CNS architectures *together*
- Future efforts need to carefully evaluate the two approaches and investigate tradeoffs between them
  - Modeling of CNS entities as agents
  - Support for CNS models at the infrastructure
- Adopting a hybrid approach
- Data collection and metrics for evaluating performance of the CNS architectures in the context of NAS need to be investigated